Exam #2

Please grade the following questions:

1, 2, 3
6, 7, 8

Circle two from each row. You must answer 4, 5, 9 and 10

Closed Book, two sheets of notes allowed
Please answer questions 4, 5, 9 and 10. In addition, answer two questions from 1-3 and two from 6-8. The total potential number of points is 100. Show all work. Be neat, and box-in your answer.

A. Water Quality & Regulations: Answer any 2 of the following 3 questions (5 points each)

1. *Standards*

State the name and key feature of the two major types of US EPA drinking water standards. Correctly name one contaminant in each category (5 points)

- Primary Standards: based on protection of human health, enforceable, examples include Giardia, Cryptosporidium, Arsenic, Lead, THMs, Benzene
- Secondary Standards: based on aesthetics, not enforceable, examples include, Taste & odor, iron, manganese, color

2. *Definition 1*

What are the meanings of the acronyms "MCL" and "TT" as related to US EPA drinking water standards? What are the key features of these standards? (5 points)

- MCL: maximum contaminant level, an enforceable standard for a particular concentration that must not be exceeded
- TT: Treatment technique; a method of treatment (e.g., CT values in disinfection) that must be used to get "credit" for the necessary removal of a contaminant or microbial, in liu of using an MCL where the contaminant must be measured on a regular basis

3. *Definition 2*

Define the term "pathogen", and give two examples. (5 points)

- Organisms (or more generally, "infectious agents") that cause disease; human pathogens are then organisms that cause disease in humans. Examples of pathogens are Giardia species, Cryptosporidium species.

B. <u>Disinfection</u>: Answer both question #4 and question #5 (30 points total)

4. Disinfection Effectiveness (7 points)

Name three of the major factors that impact the effectiveness of chemical disinfection processes used in drinking water treatment. (7 points)

Factors

- Disinfectant type
- Disinfectant dose
- Microorganism type
- Contact time
- pH
- Temperature
- Chlorine demanding substances

5. Tracer Problem (23 points)

The hydraulics of the disinfection contact tank at a water treatment plant are described by Figure 1 showing continuous (or step) input tracer study results (C_{out}/C_0 vs. time) for a flow of 1.5 MGD at a mean hydraulic detention time of 42 minutes. Some US EPA stipulated requirements for "Ct" values are described in Table 1.

Figure 1. Normalized Tracer Study Results

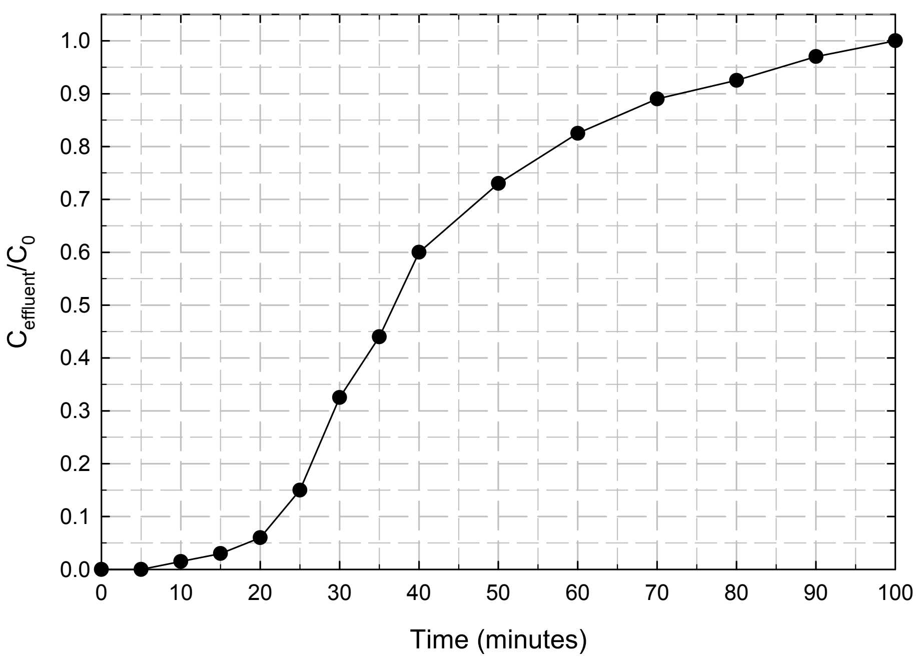

Table 1.

	Ct values (mg L^{-1} min) for *Giardia* Inactivation,

Disinfectant	water temp of 5°C	
	1 log	3 log
Free Chlorine, pH=6.0	35	105
Free Chlorine, pH=8.0	72	216
Chlorine Dioxide	8.7	26
Ozone	0.63	1.9
Chloramine	735	2200

(Ignore any chlorine concentration effects on Ct.)

a) **(7 Pts)** Why are the "Ct" values for free chlorine much higher at pH=8.0 as compared to pH = 6.0? Include chemical species in your explanation (by words or formulas).

Chlorine undergoes a conversion from more effective hypochlorous acid (HOCl) to less effective hypochlorite (OCl-) as you move from pH 6 to pH 8. The 50:50 point is at the pKa which is 7.6. Therefore you have to add more chlorine at higher pHs to get the same effect.

b) **(7 Pts)** Suppose the treatment process was disinfection only (no filtration). For the reactor hydraulics shown in Figure 1, what is the minimum allowable ozone residual in the contact tank effluent to achieve 3 log *Giardia* inactivation at a water temperature of 5 ºC?

In this case you'll need 3-log removal, which corresponds to a Ct of 1.9 min-mg/L. The "t" in Ct is actually the t_{10}. From Figure 1, we can read the t_{10} as about 22 minutes. Therefore the minimum allowable ozone residual is:

$$C = \frac{Ct}{t_{10}} = \frac{1.9}{22} = 0.086\, mg/L$$

c) **(4 Pts)** If a clever CEE 371 Engineer put baffles in the contact tank so that it behaved as a plug flow reactor, what would be the minimum allowable tank effluent ozone concentration? Explain your calculation.

In the case of an ideal PFR, all molecules of water spend the same amount of time in the contactor, so t10 is the same as the mean hydraulic detention time (42 min). Now.

$$C = \frac{Ct}{t_{10}} = \frac{1.9}{42} = 0.045\, mg/L$$

d) **(3 Pts)** Would ozone be useful as a secondary disinfectant? Explain your answer.

No it wouldn't be useful. Ozone is highly reactive and dissipates quite rapidly in water. This means it will not persist in distribution systems.

e) **(2 Pts)** Name two specific treatment processes that can be used to provide a barrier against pathogen contamination of drinking water without the addition of treatment chemicals.

Examples

- Coagulation & settling
- flotation
- Granular media Filtration
- Membrane filtration

C. Coagulation and Flocculation: Answer any 2 of the following 3 questions (6 points each)

6. Coagulants (6 points)

Name the most common chemical coagulant used in the coagulation process in drinking water treatment, and state the two main objectives of coagulation (i.e., the process of chemical addition and rapid mixing).

Alum (aluminum sulfate) is the most common coagulant in drinking water treatment. Ferric sulfate and ferric chloride are next in prevalence.

The two main objectives of coagulation are:

- Destabilization of particles, both dead and living including pathogens
- Precipitation of dissolved organic matter

In another sense, coagulation's purpose is to initiate chemical reactions that make subsequent conventional treatment more effective.

7. Power (6 points)

What power input (in kW) is required to achieve a mixing intensity (G) of 750 sec^{-1} in a mechanical rapid mixing tank with a mean hydraulic detention time of 50 seconds at a water flow of 7000 m^3/day? Assume a water temperature of 10 ºC.

Recall that:

$$P = \mu V G^2$$

So first we need to calculate the tank volume from the flow and detention time.

$$V = Qt_R = 7000\frac{m^3}{d}50sec\left(\frac{1min}{60sec}\right)\left(\frac{1hr}{60min}\right)\left(\frac{1d}{24hr}\right) = 4.05m^3$$

Now plug into the power equation

$$P = 0.001307\frac{Kg}{m-s}4.05m^3(750s^{-1})^2 = 2978\frac{Kg-m^2}{s^2}$$

And note that these units are identical to those of Watts, so the answer is:

$$P = 2{,}978 \text{ watts}$$

or

$$P = 2.978 \text{ KW}$$

8. Flocculation Design (6 points)

Consider the flocculation process used in drinking water treatment:

a. What is the main objective of this treatment process, and what is a typical design value for the mean hydraulic detention time of the process?

The main objective is to allow contact opportunities for destabilized particles to clump together (flocculate) and grow in size so that they become large enough to settle in a gravity settling tank (conventional treatment), or large enough to deposit in filters (direct filtration) or attach to fine bubbles (DAF)

30 minutes is a typical mean hydraulic detention time for flocculation

b. What are typical design values for the mixing intensity in each stage of a typical three stage tapered flocculation process? Why is this type of flocculation utilized?

Tapered flocculation mixing intensities (G values) are typically:

- $50\ s^{-1}$ in first stage
- $20\ s^{-1}$ in second stage
- $10\ s^{-1}$ in third stage

It is used so that the shear may be tapered to progressively lower values so that the progressively larger and more fragile floc can be preserved without excessive break-up

D. <u>Settling and Filtration</u>: Answer both question #9 and #10 (48 points total)

9. Settling (30 points)

A single rectangular sedimentation basin is to be designed to treat a water flow of 1.5 MGD at the design overflow rate of 900 gpd/ft^2 .

(10 Pts) Determine the basin dimensions (width, length, depth) for a detention time of 3 hours and a length to width ratio of 4 to 1. (use English units)

First calculate area from overflow rate (V_o or OFR) and flow (Q)

$$A = \frac{Q}{V_o} = \frac{1.5x10^6 \frac{gal}{d}}{900 \frac{gal}{day-ft^2}} \left(\frac{0.133 ft^3}{gal}\right) = 1667 ft^2$$

The depth is determined by the area just calculated and the volume, which we can get from the flow and retention time.

$$V = Qt_R = 1.5x10^6 \frac{gal}{d} 3hr \left(\frac{0.133ft^3}{gal}\right)\left(\frac{1d}{24hr}\right) = 25{,}000ft^3$$

$$Depth = \frac{V}{A} = \frac{25{,}000ft^3}{1667ft^2} = 15ft$$

So the area is just W*L or $4W^2$, because L/W =4, and

$$Width = \sqrt{\frac{A}{4}} = \sqrt{\frac{1667ft^2}{4}} = 20.41ft$$

And

Length = 4*Width = 4*20.41ft = 81.65 ft.

So in summary:

depth =	**15.01**	**ft**
width =	**20.41**	**ft**
length =	**81.65**	**ft**

(10 Pts) If the sedimentation tank behaves like an ideal plug flow reactor, will all particles with a 65 micron (10^{-6} m) diameter (or greater) and a density of 1200 kg/m^3 be completely removed by the ideal sedimentation tank? (water temperature is 10 ºC) Prove your answer quantitatively.

D =	65	micron =	0.000065 m
Density -	1200	kg/m3	
Temp =	10	C	

μ =	0.001307	kg/m-s	at 10C
ρ =	999.7	kg/m3	at 10C
g=	9.80665	m/s2	

Use the Stokes Equation

$$v = \frac{(\rho_p - \rho_w)D_p^2 g}{18\mu}$$

v= **0.000353 m/s =** **1.270 m/hr**

whereas the overflow rate is:

Vo= 1.525 m/hr =

the overflow rate is slightly higher, so the particle will not settle

(5 Pts) If the flow rate to the sedimentation tank increases, resulting in a higher overflow rate, would the particle removal efficiency decrease, stay the same, or increase? Briefly explain.

Particle removal efficiency would decrease, because the overflow rate would increase, narrowing the range of particle settling velocities that would be 100% retained, and decreasing the % retention on those particles with settling velocities above the overflow velocity.

(5 Pts) Suppose the depth of the sedimentation tank was reduced by 50%, and you could assume discrete particle settling. What is the effect on particle removal efficiency if the flow rate is unchanged (from the original case)? Explain your answer.

No difference, as long as the tank was behaving in an ideal fashion. This is because overflow rate dictates settling performance, and it is only a function of area and flow, but not depth. So both overflow rate and the stokes settling velocities will remain unchanged.

10. Filtration (18 points)

Consider the design and use of a dual media filter for drinking water treatment with the following characteristics:

- Anthracite Layer
  24 inch depth
  Effective Size (ES): 1.1 mm
  d_{60} size: 1.45 mm
  Porosity: 0.40

  Sand layer
  12 inch depth
  ES: 0.50 mm
  d_{60} size: 0.60 mm
  Porosity: 0.38

(2 Pts) What is the value of the Uniformity Coefficient for the sand media?

The UC is simply calculated as the ratio of the d_{60} (or ES) to the d_{10}

$$UC = \frac{0.60}{0.50} = 1.20$$

(4 Pts) If the design hydraulic loading rate is 5 gpm/ft^2, what is the approach, or superficial, velocity? Express in units of ft/min.

Vo =	5	gpm/ft2 =	**0.667**	**ft/min =**	0.0111	ft/s

(6 Pts) What is the filter surface area required, and the filter width and length, for one filter to treat a flow of 2.0 MGD at the design hydraulic loading rate? Assume a length to width ratio of 1.0. Express results in English units (ft^2 and ft).

First the area is simple obtained from the flow and filtration rate.

$$A = \frac{Q}{V_o} = \frac{2MGD\left(1.547 ft^3/_{s - MGD}\right)}{0.0111 \, ^{ft}/_{s}} = 278 ft^2$$

The since W=L, the dimensions are just the square root of the area

$$L = W = \sqrt{278 ft^2 = 16.7 ft}$$

So a 17 ft dimension would provide an adequate area and filtration rate.

(6 Pts) At the design hydraulic loading rate, what is the clean bed head loss for the anthracite media layer for a water temperature of 60 ºF? Use the Carmen-Kozeny equation with k = 5, and use the d_{60} value for media size.

The Carmen-Kozeny equation is:

$$\frac{\Delta H}{L} = \frac{36k(1-\varepsilon)^2 \nu V_0}{\varepsilon^3 d_c^2 g}$$

where ε = porosity, ν=kinematic viscosity, V_0 = filtration rate, d_c = mean media diameter, ΔH=clean bed head loss, L = bed depth, k= constant (4-5)

$$\Delta H = L \frac{36k(1-\varepsilon)^2 \nu V_0}{\varepsilon^3 d_c^2 g}$$

$$\Delta H = 2\,ft \frac{36(5)(1-0.40)^2 1.217x10^{-5} \, ^{ft^2}/_{s} \left(0.01111 \, ^{ft}/_{s}\right)}{(0.40)^3 (0.004757\,ft)^2 \, 32.2 \, ^{ft}/_{s^2}}$$

ΔH = 0.376 ft

Or if you kept metric units, it is:

$$\Delta H = 0.6096m \frac{36(5)(1-0.40)^2 1.1306x10^{-6} \, ^{m^2}/_{s} \left(0.003386 \, ^{m}/_{s}\right)}{(0.40)^3 (0.00145m)^2 \, 9.81 \, ^{m}/_{s^2}}$$

ΔH = 0.1146 m

Good stuff to know

<u>Conversions</u>

7.48 gallon = 1.0 ft^3 1 gal = 3.7854×10^{-3} m^3
1 MGD = 694 gal/min = 1.547 ft^3/s = 43.8 L/s
1 ft^3/s = 449 gal/min
g = 32 ft/s^2
W=γ = 62.4 lb/ft^3 = 9.8 N/L
1 hp = 550 ft-lbs/s = 0.75 kW
1 mile = 5280 feet 1 ft = 0.3048 m
1 watt = 1 N-m/s
1 psi pressure = 2.3 vertical feet of water (head)
At 60 ºF, $\nu = 1.217 \times 10^{-5}$ ft^2/s

Water Properties:
At 60 ºF, $\nu = 1.217 \times 10^{-5}$ ft^2/s , $\mu = 2.359 \times 10^{-5}$ $lb\text{-}sec/ft^2$, $\gamma = 62.4$ lb/ft^3
At 10 ºC, $\nu = 1.306 \times 10^{-6}$ m^2/s , $\mu = 1.307 \times 10^{-3}$ kg/m-s , $\rho = 999.7$ kg/m^3

PHYSICAL AND CHEMICAL CONSTANTS

Avogadro's number	$\mathcal{N} = 6.022 \times 10^{23}\ \text{mol}^{-1}$
Elementary charge	$e = 1.602 \times 10^{-19}\ \text{C}$
Gas constant	$R = 8.314\ \text{J mol}^{-1}\ \text{K}^{-1}$
	$= 1.987\ \text{cal mol}^{-1}\ \text{K}^{-1}$
	$= 0.08205\ \text{L atm mol}^{-1}\ \text{K}^{-1}$
Planck's constant	$h = 6.626 \times 10^{-34}\ \text{J s}$
Boltzmann's constant	$\mathbf{k} = 1.381 \times 10^{-23}\ \text{J K}^{-1}$
Faraday's constant	$F = 9.649 \times 10^{4}\ \text{C mol}^{-1}$
Speed of light	$c = 2.998 \times 10^{8}\ \text{m s}^{-1}$
Vacuum permittivity	$\varepsilon_0 = 8.854 \times 10^{-12}\ \text{J}^{-1}\ \text{C}^2\ \text{m}^{-1}$
Earth's gravitation	$g = 9.806\ \text{m s}^{-2}$

CONVERSION FACTORS

1 cal	= 4.184 joules (J)
1 eV/molecule	$= 96.485\ \text{kJ mol}^{-1}$
	$= 23.061\ \text{kcal mol}^{-1}$
1 wave number (cm^{-1})	$= 1.1970 \times 10^{-2}\ \text{kJ mol}^{-1}$
1 erg	$= 10^{-10}\ \text{kJ}$
1 atm	$= 1.01325 \times 10^{5}\ \text{Pa}$
1 Å	$= 10^{-10}\ \text{m}$
1 L	$= 10^{-3}\ \text{m}^3$

PROPERTIES OF WATER

T(°C)	ρ, Density ($\text{kg} \cdot \text{m}^{-3}$)	μ Viscosity ($\text{kg} \cdot \text{m}^{-1} \cdot \text{s}^{-1}$)	σ, Surface Tension against Air ($\text{J} \cdot \text{m}^{-2}$)	ε Dielectric Constant ($\text{C} \cdot \text{V}^{-1} \cdot \text{m}^{-1}$)	pK_w, Ionization Constant ($\text{mol}^2 \cdot \text{L}^{-2}$)
0	999.868	0.001787	0.0756	88.28	14.9435
5	999.992	0.001519	0.0749	86.3	14.7338
10	999.726	0.001307	0.07422	84.4	14.5346
15	999.125	0.001139	0.07349	82.5	14.3463
20	998.228	0.001002	0.07275	80.7	14.1669
25	997.069	0.0008904	0.07197	78.85	13.9965
30	995.671	0.0007975	0.07118	77.1	13.8330

SI PREFIXES

Multiplication Factor	Prefix	Symbol	Multiplication Factor	Prefix	Symbol
10^{12}	tera	T	10^{-2}	centi	c
10^{9}	giga	G	10^{-3}	milli	m
10^{6}	mega	M	10^{-6}	micro	μ
10^{3}	kilo	k	10^{-9}	nano	n
10^{2}	hecto	h	10^{-12}	pico	p
10^{1}	deka	da	10^{-15}	femto	f
10^{-1}	deci	d	10^{-18}	atto	a